SYNTHESIS AND CHARACTERIZATION OF NANOMATERIALS FOR DETECTION OF MICROBIAL COMPONENTS IN AMBIENT ENVIRONMENT

A

Synopsis

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Introduction

Air Pollution poses an enormous threat to human health and the environment. Aerosols play a vital role and affect human health and climate. The health effects of aerosols depend upon the chemical and biological components of aerosols. The biological components of aerosols are known as bioaerosols. Bioaerosols include microorganisms (like; bacteria, viruses, fungi, etc.), pollens, biofilms, etc. They infect humans, plants, and animals and are estimated to be responsible for more than 15 million deaths worldwide each year. The present pandemic situation due to SARS-COVID and the production of biological warfare agents has posed threats to the safety and security of human beings. However, detection of biological components in ambient air is a difficult challenge as the methods are cumbersome and time taking. Hence, the development of fast and accurate methods of detection and identification systems for biological components in the environment is of paramount importance in the current scenario of the infection and spread of pathogens. Sensor-based techniques may be an important tool to sense the changes in the biological environment and to provide alerts of possible harm in real-time against pathogens.For environmental monitoring, it is necessary to find a simple, rapid, cost-effective, and field-portable screening method to monitor various biological and chemical contaminants which can be potential risks to human health (Rogers, 2006; Steinberg et al.,1995; Belkin, 2003). The food and fermentation industries need rapid, affordable, and reliable methods to ensure the quality of products and process controls (Belkin,2003; Arora et al., 2011). There is also an urgent need in clinical diagnostics for accurate, fast, and inexpensive devices, which can be routinely used to monitor clinically important parameters (Malhotra and Chaubey, 2003; Ivnitski et al., 1999). The conventional methods in those applications typically require analytical techniques, specialized laboratories, and practiced operators, which are costly, complicated, and time-consuming.A biosensor is an analytical device that combines the biological recognition element with a signal transducer to convert the response with analytes into a measurable signal which is proportional to the concentration of the analytes (Chauhan et al., 2004). A microbial biosensor is a sensor that uses microorganisms that consists of numerous enzymes as the elements (Figure 1) (Prasad et al, 2017). To transfer the responses from the recognition

elements to the transducers, the immobilization between the bioelements and the transducers must be intimate and stable.

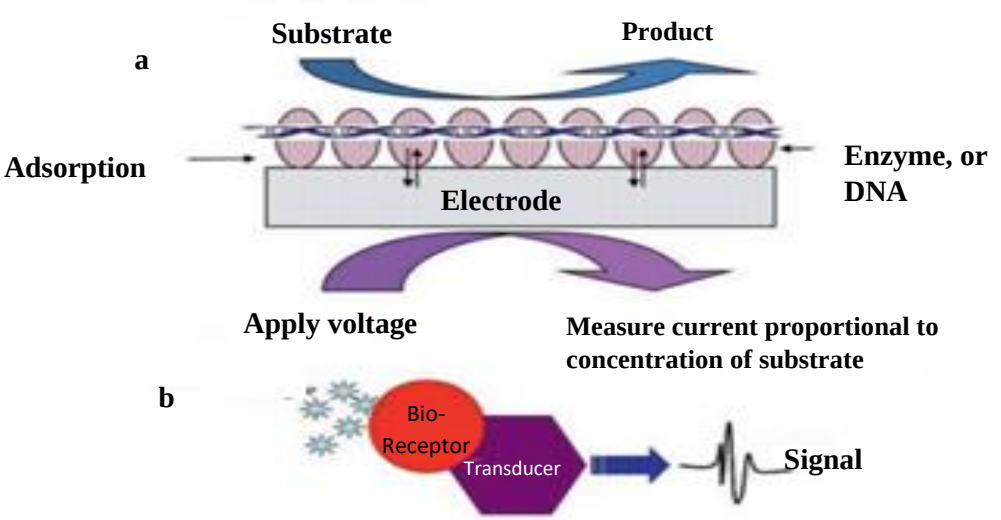

Figure 1. A schematic representation of microbial biosensor

Nanomaterials have enabled advances in sensor design such as miniaturization, portability, and rapid signal response times. High surface area to volume ratios and facile surface functionalization make nanomaterials highly sensitive to changes in surface chemistry thus enabling nanosensors to achieve extremely low detection limits. In the past few decades, nanomaterial-based sensors and biosensors have experienced rapid developments thanks to the advancements in material synthesis and characterization (Rosi and Mirkin, 2005). Among various materials, gold and silver (Chauhan et al., 2004; Prasad et al., 2017; Su et al., 2011), and carbon-based materials (Giljohann et al., 2010; Zhao et al., 2008., Liu et al., 2017; Wang et al., 2012) have been the most frequently used. The excellent optical, electric, and catalytic properties of gold nanoparticles are very useful for designing biosensors (Xiao et al., 2003, Rosi and Mirkin, 2005; Luo et al., 2010; Tan et al., 2014; Lim et al., 2015). However, gold is expensive, and its surface is quite susceptible to contamination leading to less reproducible sensor performance.Recently, metal oxide materials have been integrated into novel biosensing devices (Figure 2), since they exhibit enhanced electron-transfer kinetics and strong adsorption capability. These have a high potential to become highly competitive materials in the biosensors market, based on their morphologic versatility (Song et al., 2020), chemical stability (Hernández et al., 2015), physicochemical interfacial properties (Scognamiglio et al., 2019), and their ability to combine in composite structures

(Zheng et al., 2020). Among others, TiO_2 (Wang et al., 2019), WO_3 (Liu et al., 2015), SnO_2 (Dong and Zheng, 2014), and ZnO (Zheng et al., 2020) have attracted considerable attention due to their electrochemical sensitive properties (Enesca et al., 2012a) and energy band alignment (Enesca et al., 2012b) suitable for enzyme-based biosensors.

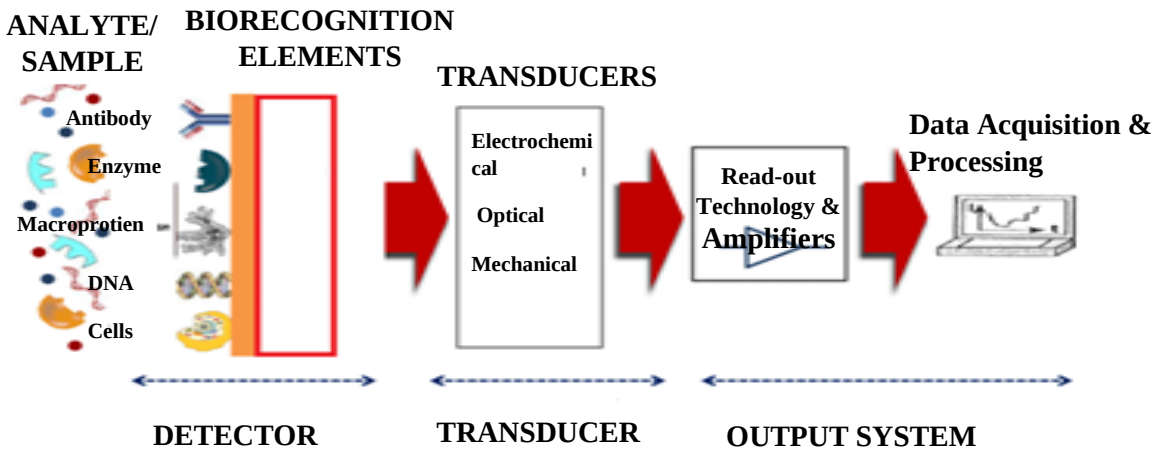

Figure 2. Metal Oxide biosensor design

The advantage of these materials is cost-effective synthesis methods such as co-precipitation (Dong and Zheng, 2014), sonochemical precipitation (Zhou et al., 2013), thermal oxidation (Li et al., 2010), chemical etching (Liu et al., 2010), polyol (Elahi et al., 2019), hydrothermal (Zhou et al., 2017), or sol-gel (Rathinamala et al., 2019) allowing the formation of various morphologies such as porous quasi-nanospheres (Liu et al., 2017), hollow nano-spheres (Santos et al., 2016), nanorods (Dong et al., 2017), nanosheets (Zhang et al., 2020), or flower-like particles (Feng et al., 2018). Additionally, these materials can be combined between them or with others to form tandem heterostructures (Enesca et al., 2015), hybrid structures (Mihaly et al., 2008), or composite structures (Visa et al., 2016) with advanced electrochemical properties which can be adapted to a specific biosensor application. Different types of structures can be obtained by using different methods of synthesis such as chemical vapour deposition, sol-gel, radio frequency sputtering, hydrothermal, electro-spinning, molecular beam epitaxy, template synthesis, metal-organic chemical vapour deposition (MOCVD), etc. The sensing response can be improved by metal doping into MOx, functionalization of noble metal nanoparticles on MO surface, the inclusion of carbonaceous nanostructures, the composition of different MOx nanostructures, UV activation, and e-beam irradiation.

REVIEW OF LITERATURE

Research work in generating an effective and reliable sensor film for the detection of microbial components has been going on all over the world. A literature survey has been carried out and a summary of work done on the development of thin films/sensors for monitoring microbial components nationally and internationally are presented.

International Status

Jiang et al. (2020) showed concern that COVID-19 poses an enormous threat to the safety of human beings and animals.

Ali et al. (2020) reviewed the effectiveness of various forms of sensing technologies for the detection of food-borne pathogens in food products, as well as the criteria for industrial use of this technology.

Jung et al. (2020) developed a GO-based immuno-biosensor for detecting rotavirus as a pathogen model. The detection occurs with high sensitivity and selectivity by GO photoluminescence quenching induced by fluorescence resonance energy transfer (FRET) between GO sheets and AuNPs.

You et al. (2020) developed a one-step laser induction method to prepare various noble metal nanoparticle-3D graphene nanocomposites. The immunosensor shows excellent performance including low detection limit, high selectivity, and great flexibility.

Nguyen et al. (2020) studied the application of nanomaterials in colorimetric paper-based biosensors for pathogen detection. They discussed the sensing mechanisms of working, structural and analytical characteristics of the devices, and representative recent applications.

Brauner et al. (2014) explored that indoor aerosol concentrations in areas could be targeted by malicious attacks of bioterrorism including assembly spaces as well as the transport sector. They studied the ranges of the typical indoor aerosols which can be used as a reference in designing biosensors used for the improvement of public security.

Bordbar et al. (2020) developed a sensor for the quantitative measurement of pesticide aerosols at a very low concentration. The statistical results confirmed that the method has high performance for concurrent detection of thions as a major air pollutant without the interference of other species.

Antiochia (2020) summarized the state of the art of nanotechnology-based affinity biosensors for SARS, MERS, and COVID-19 detection. A critical comparison with conventional methods, such as RT-PCR and ELISA, were also reported.

Zhang et al. (2020) summarized the advanced biosensors, including electrochemical, colorimetric, fluorescent, and surface-enhanced Raman scattering biosensors for sensing key food-borne pathogens in recent decades.

Su et al. (**2020)** discussed the analytical technologies and sensors for PMs and bioaerosols. Using Influenza, A (H_1N_1) virus and SARS-CoV-2 (COVID-19) virus they highlighted air sampling and detection challenges for viral aerosols relative to bacterial and fungal aerosols.

Qiu et al. (2020) developed a localized surface plasmon resonance biosensor based on succinimidyl-ester-functionalized gold nanoislands (SEF−AuNIs) for quantitative bioaerosol detection. The results substantiated that SEF−AuNI sensors could be a reliable candidate for total bioaerosol detection and air quality assessment.

Alhalaili et al. (2020) explored the progress made in the development of nanobiosensors for the detection of human corona viruses (SARS-CoV, SARS-CoV-2, and Middle East respiratory syndrome corona virus (MERS-CoV) along with specific techniques for modifying the surface of nanobiosensors.

Batool et al. (2019) discussed the possible constructs of nano-hybrids and their subsequent use in the construction of electrochemical glucose biosensors. The modification of a working electrode with a combination of two or three nanomaterials in the form of nano-composite/nano-hybrids had revealed good results with very good reproducibility, stability, and improved sensitivity.

Tian et al. (2020) explored bioaerosol emissions from wastewater treatment plants (WWTP) and employed a novel real-time bioaerosol sensor, Spectral Intensity Bioaerosol sensor (SIBS) at a WWTP background site. The findings confirmed that the spectrally resolved fluorescence detected by SIBS is capable of better characterization of bioaerosols in real-time.

Cui et al. (2020) summarized and discussed biomarkers/indicators for diagnosis of corona virus disease 2019 (COVID-19) or detection of severe acute respiratory syndrome corona virus 2 (SARS-CoV-2) in the environment.

Qiu et al. (2020) investigated dual-functional plasmonic biosensor combining the plasmonic photothermal (PPT) effect and localized surface plasmon resonance (LSPR) sensing transduction which provides an alternative and promising solution for the clinical COVID-19 diagnosis with a lower detection limit down to the concentration of 0.22 pM and allows precise detection of the specific target in a multigene mixture.

Jiang et al. (2020) developed graphene biosensors for the detection of bacterial and viral pathogens, mainly including the preparation of graphene biosensors and their working mechanism.

Meraat et al (2020) used zinc oxide nanoparticles (ZnO NPs) and multi-wall carbon nanotubes (MWCNTs) as marker molecules. They observed MWCNTs exhibited better performance than ZnO NPs in the detection of bacteria at a very low concentration of 101 CFU/ml in 15 min.

Şerban et al. (2020) worked on the implementation of a metal oxide semiconductor (MOS) in biological and environmental systems. Four representative metal oxides (TiO_2, ZnO, SnO_2, and WO_3) were presented based on several aspects: synthesis method, morphology, functionalizing molecules, detection target, and limit of detection (LOD).

Sun et al. (2009) developed a new procedure based on photo deposition of nano-Ag at TiO_2-coated piezoelectric quartz crystal (QPC) electrode to fabricate a highly sensitive PQC/DNA biosensor.

Fiorani et al. (2019) studied the importance of a rational modification and functionalization of carbon nanomaterials to optimize electrochemiluminescence signals.

Nunes et al. (2019) studied sensors based on zinc oxide (ZnO), titanium dioxide (TiO_2), tungsten trioxide (WO_3), copper oxide (CuO and Cu_2O), tin oxide (SnO and SnO_2), and vanadium oxide (VO_2 and V_2O_5), either as nanoparticles or as continuous films or layers. They correlated sensing properties to size, shape, presence of defects, and doping elements, amongst other relevant parameters.

Liu et al. (2019) studied fundamental surface properties of MONMs, especially interactions with DNA, and they also discussed a few sensing strategies including the modulation of the catalytic activities of MONMs, and competitive adsorption.

Saito et al. (2018) developed an autonomous air sampling and detection system for the evaluation of the presence of chemical and biological warfare agents.

Ariffin et al. (2018) developed a novel electrochemical DNA biosensor for ultrasensitive and selective quantification of *Escherichia coli* DNA based on aminated hollow silica spheres (HSiSs). The improved performance of the DNA biosensor appeared to be due to the hollow structure and rough surface morphology of the hollow silica particles.

Zeng et al. (2018) summarized the principles and the application of some recent rapid detection technologies for pathogenic bacteria.

Willner et al. (2018) introduced nanosensor design before exploring the application of nanosensors for the detection of three classes of environmental contaminants: pesticides, heavy metals, and pathogens.

Mocan et al. (2017) reported that disease-related biomarkers can be rapidly and directly detected by nanostructures, such as nanowires, nanotubes, nanoparticles, cantilevers, microarrays, and nanoarrays, as part of an accurate process characterized by lower sample consumption and considerably higher sensitivity.

Neethirajan et al. (2017) studied POC device which involves technologies such as microfluidics, nanomaterials, biosensors, and other advanced techniques.

Meral et al. (2017) studied characterization techniques that have been practiced to validate nanoparticle surface modification with antibodies and aptamers, including gel electrophoresis, ultraviolet-visible spectrophotometry, dynamic light scattering, and circular dichroism.

Yuce et al. (2017) constructed and characterized nano biosensors that were based on widely used affinity probes including antibodies and aptamers and nanomaterials such as carbon-based nanomaterials, plasmonic nanomaterials, and luminescent nanomaterials.

Sutarlie et al. (2016) highlighted the principles of nanomaterials-based biosensors for four selected analyte categories (bacteria cells, toxins, mycotoxins, and protozoa cells), closely associated with the target analytes properties. Signal transducing methods were described and compared for their sensory performance (in terms of limit of detection, dynamic range, and response time) for all analyte categories.

Rowland et al. (2016) studied an overview of bioagents and highlighted the breadth of nanoscale sensors that have recently emerged for their detection.

Rowland et al. (2016) developed nanomaterial-based biosensors with sensitivity and accuracy that were starting to surpass traditional biothreat detection methods, with reduced sample volume, preparation time, and assay cost.

Khan et al. (2016) developed liquid-crystal (LC)-filled transmission electron microscopy (TEM) grid cell coated with the cationic surfactant dodecyl trimethyl ammonium bromide (DTAB), to which a single-stranded deoxyribonucleic acid probe (ssDNAprobe) was adsorbed at the LC/aqueous interface (TEMDTAB/DNA) and was applied for the highly specific detection of target DNA molecules

Ivanir et al. (2016) designed an optical biosensor for the identification and quantification of *Escherichia coli* in complex food industry process water. The biosensors were capable of selectively identifying and quantifying the target cells, while the target cell concentration is in orders of magnitude lower than that of other bacterial species, without any pre-enrichment or prior processing steps.

Fronczek et al. (2015) investigated portable biosensors and/or micro total analysis systems (μTAS) that can be used for monitoring such airborne pathogens, similar to smoke detectors.

Zhao et al. (2015) studied electrochemiluminescent (ECL) and photoelectrochemical (PEC) properties and mechanisms of semiconductor quantum dots (QDs) with emphasis on their specific fundamentals and concise comparison of their similarities and differences.

Wang et al. (2015) designed a nanoparticle-labeled biosensor for the rapid detection of *E. coli* O157:H7 in broth. They showed a sensitivity of 10^1 colony-forming units per milliliter (CFU/ml) with a linear range of 10^1 –10^6 CFU/ml.

Wang et al. (2015) developed an electrochemical immunosensor based on the assembly of three nanoparticles for the rapid detection of *Escherichia coli* O157:H7. They showed that the biosensor could detect *E. coli* O157:H7 in the range of 10 1 -10 6 colony-forming units per milliliter (CFU/ml) with a signal-to-noise ratio ranging from 2.77 to 4.31.

Cho et al. (2013) investigated an *in-situ* immuno-AuNP network-based ELISA biosensor integrated with a sample concentration step based on immuno-magnetic separation to detect pathogenic microorganisms with high sensitivity.

Zuo et al. (2013) developed a polydimethylsiloxane (PDMS)/paper/glass hybrid microfluidic system integrated with aptamer-functionalized graphene oxide (GO) nano-bio sensors for simple, one-step, multiplexed pathogen detection.

Dai et al. (2013) focused on the newly developed technologies and applications of microbial biosensors in recent years.

Sassolas et al. (2012) studied recent advances and new trends in biosensors for pesticide detection. The incorporation of nanomaterials provided highly sensitive sensing devices allowing the efficient detection of pesticides.

Mura et al. (2012) developed mesoporous titania thin-film substrates as sensors to detect *E. coli*. The film-based biosensors showed a detection limit for *E. coli* of 1×10^2 CFU/mL, constituting a simple and selective method for the effective screening of water samples.

Lee et al. (2012) studied the overview of the various nanomaterial-based biosensors that utilize different biological recognition elements for biomedical applications.

Xu (2012) studied the development and application of electromechanical biosensors for pathogen detection. They have also discussed sensing principles, immobilization of biorecognition elements, and applications to the detection of pathogens in food and water samples.

Baeumner et al. (2012) developed a highly sensitive and specific RNA biosensor for the rapid detection of viable *Escherichia coli* as an indicator organism in water, which can detect as few as 40 E. coli CFU/ml.

Hao et al. (2011) developed a DNA probe functionalized quartz crystal microbalance (QCM) biosensor to detect *B. anthracis* based on the recognition of its specific DNA sequences, i.e., the 168 bp fragment of the Ba813 gene in chromosomes and the 340 bp fragment of the *pag* gene in plasmid pXO1. To amplify the signal, a thiol-DNA fragment complementary to the other end of the target DNA was functionalized with gold nanoparticles.

Li et al. (2011) prepared magnetic Fe_2O_3@Au nanoparticles by reducing $HAuCl_4$ on the surfaces of Fe_2O_3 nanoparticles. The biosensor could detect the concentrations upper than 0.01 pM DNA target and upper than 500 CFU ml^{-1} of *E. coli* without any nucleic acid amplification steps.

Zhang et al. (2010) developed a highly amplified, nanoparticle-based bio-barcoded electrochemical biosensor for the simultaneous multiple detections of the protective antigen A (pagA) gene (accession number, M22589) of *Bacillus anthracis* and the insertion element (Iel) gene (accession number, Z83734) of *Salmonella enteritidis*.

Kamikawa et al. (2010) developed electrically active magnetic (EAM) nanoparticles, consisting of aniline monomer polymerized around gamma iron (III) oxide (-Fe_2O_3) cores, serve as the basis of a direct-charge transfer biosensor for detection of surface glycoprotein hemagglutinin (HA) from the Influenza A virus (FLUAV) H_5N_1 (A/Vietnam/1203/04). H5N1 preferentially binds 2,3-linked host glycan receptors.

Sanvicens et al. (2009) studied the progress, limitations, and future challenges of NP-based biosensors for the detection of pathogenic bacteria.

Heo et al. (2009) focused on newly developed nano- and micro-scaled biosensors, novel sensing modalities utilizing microfluidic lab-on-a-chip, and array technology for the detection of pathogenic bacteria. These technologies allowed for a great improvement of detection limit, therefore, reduce the time required for sample preparation.

Yogeswaran et al. (2008) reviewed the development and application of nanowires for electrochemical sensors and biosensors.

Lu et al. (2008) synthesized a nanosheet-based ZnO microsphere with porous nanostructures by a facile chemical bath deposition method followed by thermal treatment, which was explored for the construction of electrochemical biosensors.

Pingarrón et al. (2008) studied electrochemical immunosensors in which gold nanoparticles play a crucial role in the electrode transduction enhancement of the affinity reaction as well as in the efficiency of immunoreagents immobilization in a stable mode.

Merkoci (2006) reviewed the latest trends in the use of nanoparticles (NPs) in electrochemical biosensing systems. They also highlighted that electrochemical NPs can also be used in designing immunoassays, offering the possibility of easy, low cost, and simultaneous detection of several proteins.

Rogers (2006) worked on biosensors for environmental applications which showed advances and improvements in areas such as sensitivity, selectivity, and simplicity.

Ivnitsk et al. **(1999)** focused on recent advances in the development of alternative enzyme- and immunosensors for the detection of pathogenic bacteria in a variety of fields. Special attention was paid to methods for improving the analytical parameters of biosensors including sensitivity and analysis time as well as automation of assay procedures.

National status

Kabir et al. (2020) studied the mechanisms of conventional and advanced bioaerosol detection methods. They emphasized the limitations of current technology as most of the currently available options tend to suffer from lengthy sample acquisition times and/or nonspecificity of probe material.

Kumar et al. (2020) reported the different sensing methods used in food borne pathogen detection, their design, working principle, and advances in sensing systems.

Choudhary (2019) focused on the application of biosensors for contaminants in the food system.

D'Souza et al. (2017) summarized an overview of the contribution of nanotechnology-based biosensors in the food industry.

Bhattacharya et al. (2017) reported the theoretical explanation of fluorescence phenomena including the sensing mechanism followed by the use of optical nanosensors like quantum dots, and finally the utilization of these quantum dots for sensing food pathogens and toxins.

Singh (2016) emphasized the need for the evolution of nano biosensor-based bioanalysis which has resulted in substantial progress in its analytical performance and bio-detection applications.

Poongodi et al. (2015) deposited cobalt-doped ZnO thin films on glass substrate by sol-gel spin coating technique. The optical density (OD) measurement showed better bactericidal activity at a higher level of Co doping in ZnO.

Malhotra et al. (2014) fabricated nanomaterial-based biosensors for food toxin detection obtained in their laboratories.

Sisodia et al. (2013) discussed important features of nano-particle biosensors and R & D bibliometric analysis. R & D bibliometric analysis showed that gold nanoparticles were the best in class.

Malik et al. (2013) highlighted the different types of biosensors based on different types of nanomaterials and their developmental and implicational aspects.

Gautam et al. (2012) summarized recent advances made in the detection and quantification of waterborne contaminants with different types of biosensors that offer capabilities for rapid, miniaturized online and in-situ analysis with minimal waste production.

Khanna (2008) detected methodologies for various warfare agents using nanoparticle-based sensors. Gold nanoparticles were coated with sugars tailored to recognize different biological substances.

Numerous efforts have been made and works are in progress on the detection and characterization of microbial components in the environment. But, only limited studies have been reported on the detection of microbial components in the ambient air even though the microbial components are transmissible in air.

Objective

Bioaerosols in the form of microscopic airborne particles pose pervasive risks to humans and livestock; however, they are among the least investigated pollutants in nature either as fully active components (e.g., viruses, bacteria, and fungi) or as whole or part of inactive fragments. Their identification and quantification are essential for addressing related dangers and establishing proper exposure thresholds; however, there is a lack of detection techniques and standardized procedures for the sensing bioaerosols. The development of sample collection and sensing technology made it possible for continuous and automated operations. However, intensive efforts are required to overcome the limitations of current technology in view of present pandemic due to COVID 19, fear of more microbial disease in coming future and expectation of increase in use of biological warfare agents. Advancements in sensor technology as well as in aerosol collectors will enable for true bioaerosol sampling for continuous and automated biosensors. Hence, there is a need for a study dealing with the development of cost-effective and highly sensitive biosensors for the detection of the biological component in the ambient air. With this, in view, the aim of the present investigation is:

- to synthesize thin film for detection of bioaerosols,
- to characterize synthesized thin-film material using SEM-EDS and AFM (for shape, size, surface roughness, and arrangement of constituent particles), XRD (for phase analysis and particle size), and different spectrometer techniques to find the bandgap, etc.
- to measure and enhance the biosensing efficiency of developed material and

- to monitor and measure aerosol particles (like $PM_{10}/PM_{2.5}/PM_{1.0}$) and their biological components using culture technique and comparison

Material and methods

The thin-film based on metal oxide will be prepared, characterized and efficiency will be improved by doping and decoration.

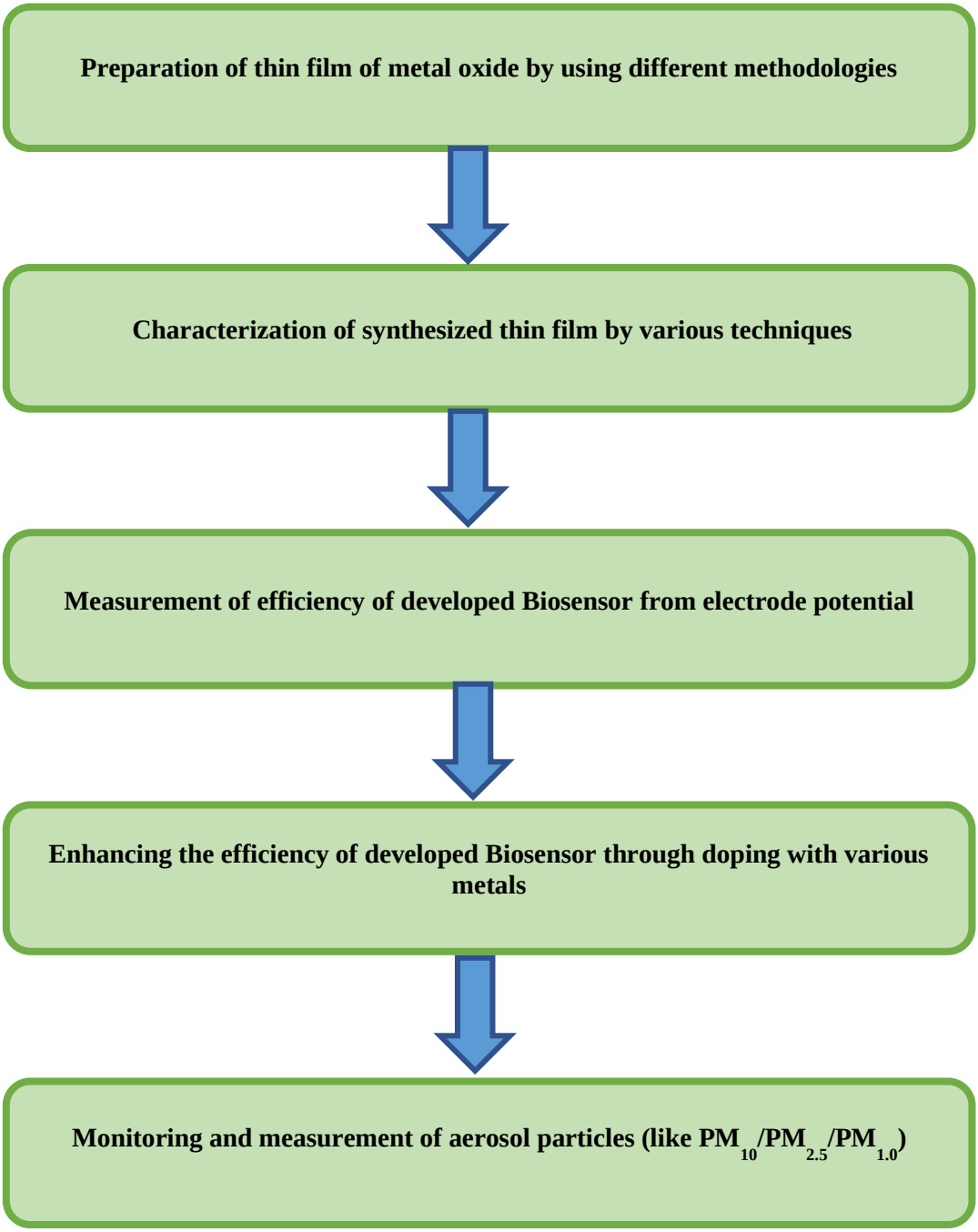
Preparation of thin film of metal oxide by using different methodologies
Characterization of synthesized thin film by various techniques
Measurement of efficiency of developed Biosensor from electrode potential
Enhancing the efficiency of developed Biosensor through doping with various metals
Monitoring and measurement of aerosol particles (like PM10/PM2.5/PM1.0)

Figure 3: Schematic flow diagram for the synthesis of metal oxide biosensor

Preparation of thin films

Thin films of ZnO/La_2O_3 will be prepared to fabricate the biosensors for monitoring and measurements of bioaerosols in the environment. Compared with other metal oxides ZnO/La_2O_3 NPs are comparatively inexpensive, relatively less toxic, have a high surface-to-volume ratio, show good compatibility, chemical stability, and proper electron exchange, which makes them suitable for use in biosensors. Desired nanostructure (Nanorods/nanotubes/nanowires etc.) will be obtained by growing nanomaterial using the Sol-Gel method because of its high surface to volume ratio and miniaturization capability that helps in achieving low-temperature pathogen sensing, enhance sensitivity and stability.

Material characterization

The structural and morphological characterization of nanomaterial will be carried out using SEM, EDX, FESEM, XRD, and Raman Spectroscopy. The morphological (size, shape, and surface) study will be performed using SEM and TEM (nature of bonds too). X-ray diffraction techniques will be used for structural and phase analysis. The size of the particle would be determined using the Scherrer equation ($0.9\lambda/\beta\cos\theta$). The thickness of the film will be determined by using a surface profilometer. Bandgap will be determined by plotting $(\alpha\lambda\gamma)^{1/2}$ versus $h\upsilon$ using the equation $\alpha = A\ (h\upsilon - Eg)^{1/2}$. UV-visible Spectrometer will be used to obtain absorption data. Raman spectroscopy yields information about intra- and inter-molecular vibrations

Sensing measurement

Sensing measurement will be done through the measurement of electrode potential. PEC bioanalysis based on biological interactions between various recognition elements and their corresponding targets via current/voltage with an array of electrodes will be performed. The biological recognition systems transfer the biochemical information (e.g. an analyte concentration) into a variation in the specific factor like resistance, voltage, current, and sensitivity on or surrounding the electrodes, the change will be associated with the PEC active species. The transducer would subsequently convert the physical-chemical interactions between the biological recognition systems and PEC active species to the electrical signal.The pathogen sensing characterization of sensors will be done in a customized pathogen sensing chamber. The pathogen sensing characterization will be carried out for a range of concentrations at optimized operating temperature. The developed sensor will be used for monitoring biological

components in the environment. The data will be collected, analyzed, and compared with data obtained through other methods or instruments.

Efficiency enhancement through Doping: Doping to the metal oxide (ZnO/La_2O_3) semiconductor with different metals like transition metal (Ni/Cr), rare earth metal (Yb/La), and noble metal (Pd/Pt) has attracted great attention to enhance the sensing properties of biosensors. The doping to the metal oxide semiconductor will be done to increase the catalytic activity and change the resistance of host metal oxide. The dopants will be distributed uniformly throughout the host metal oxide matrix. Oxygen ions are formed on the interaction of oxygen molecules to these dopants and then spill over on the entire metal oxide surface during exposure to air. On exposure of target pathogen to the metal oxide, oxygen ions react and resulting in a large change in the conductivity as well as sensitivity. Enhancement in sensitivity is due to the reduction in grain, which correspondingly increases the surface area. The biosensing, electronic and chemical properties of doped metal oxide semiconductors become quite different as compared to pure metal oxide semiconductors. These dopants have been chosen to keep in mind their cost and sensitivity.

Monitoring and measurement of aerosol particles (like $PM_{10}/PM_{2.5}/PM_{1.0}$) and their biological components and comparison

Measurements of particle composition using offline methods typically involve the collection of particles on substrates for a defined period using different sampling techniques such as filters. Ambient air will be drawn through a filter material using a pump and then collected samples will be transferred to the laboratory for extraction and biological analysis. Conventional cell culture and colony counting (CFU m^{-3}) will be performed to estimate the number of viable bacteria or fungal cells in a sample. The same exercise would be repeated with the developed sensor and the result would be compared on the grounds of sensitivity, versatility, and durability.

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